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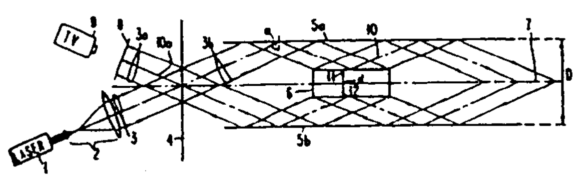
(54) Interferometric thickness analyzer and measuring method.

(57) Flat objects (6), e.g. non-transparent wafers, are tested over their entire surface for thickness variations in an interferometric set-up (Fig. 1) where symmetrical opposite points on the front and rear surface, resp. are sensed by the same light ray (10). A laser beam (3) impinges under oblique angle of incidence on a beam splitter (e.g. a grating 4) to generate a reference beam (3a) and a measurement beam (3b). The latter is directed by a first of a pair of plane mirrors (5a) to the front surface of sample (6) from which it is reflected again to plane mirror (5a) to reach blazed grating (8) which deflects it symmetrically to plane mirror (5b). The rear surface of sample (6) is thus illuminated under the same angle of incidence in a way that each ray (10) is directed to the point on the rear surface that is exactly opposite to its reflection point at the front surface. The beam reflected at the rear surface passes after further reflection at plane mirror (5b) through beam splitter (4) in the same direction as reference beam (3a) thus generating an interference pattern on screen (8). The fringe separation in the interference pattern is representative of the local thickness of sample (6) and can be evaluated electronically or by pattern recondition methods to thickness readings with an accuracy of $\lambda/200$. A second embodiment of the invention uses a folded mirror instead of blazed grating (7) for the



INTERFEROMETRIC THICKNESS ANALYZER AND MEASURING METHOD

The invention relates to a method for interferometrically determining thickness variations in flat objects and to an apparatus for carrying out the method. A preferred use of the invention is in the fields of manufacturing integrated circuits and high density magnetic disks.

Modern manufacturing methods with accuracies in the range of micrometers require substrates whose thickness is controlled to the same tolerance. A particular example is in the field of photolithography where wafers with extremely plane surfaces have to be mounted in exact parallelism on the support, e.g. a chuck. Thickness variations in the wafer of one micrometer or less can lead to unacceptable overlay errors and hence to yield losses. The same problems may arise due to the limited depth of focus in high resolution optical printers.

One known method of measuring substrate thickness uses a mechanical stylus or inductive or capacitive probes to measure selected points at the surface or to scan along lines so that no complete thickness distribution of the whole surface is obtainable. In addition the surface may be damaged by the probes.

Reflecting substrates can be tested for thickness variations in an interferometric set-up with normal light incidence; for that purpose the substrate is firmly attached or clamped to a reference plane, e.g. on a chuck. This method, however, is not applicable to sensitive substrates that may be damaged by the chuck.

It is therefore the object of the present invention to provide a method and an apparatus of the aforementioned kind that allow an accurate, contactless and full area determination of the thickness distribution in a substrate.

This object is achieved by the invention as characterized in claims 1 and 2; embodiments of the invention are characterized in the dependent claims.

The invention proposes an interferometric set-up in which each ray is reflected at exactly opposite points on the front and back surfaces of the substrate, resp. before being brought to interference with a reference ray. Diffusely reflecting substrates can be measured by choosing sufficiently large angles of incidence. A very high resolution in the order of $\lambda/200$ is obtainable if the resulting interference pattern is evaluated by known electronic means. The interferometric set-up itself is of relatively simple design and can easily be used for rapid screening of all substrates entering or leaving a production line.

Embodiments of the invention will now be described in detail with reference to the drawings wherein:

Fig. 1	shows in schematic representation a first embodiment of the invention with a blazed grating;
Fig. 2	shows the ray path when a bent substrate is measured in a set-up according to Fig. 1;

Fig. 3 shows a schematic representation of a second embodiment of the invention using a foldable mirror; and

Fig. 4 shows the embodiment of Fig. 3 using an increased angle of incidence.

Fig. 1 shows in schematic representation the optical set-up of a first embodiment of the invention where a blazed grating is used for beam deflection. The output beam of laser 1 is expanded in lens combination 2 to a collimated beam 3 which is split by beam splitter 4 in a first partial beam 3a which serves as a reference beam and a measurement beam 3b. The beam splitter may be a semireflecting glass plate or an optical grating. The object 6 to be measured is arranged between two flat mirrors 5a, 5b whose flatness is of better than $\lambda/20$. The angle of incidence α of measurement beam 3b is chosen such that it illuminates the (entire) upper surface of sample 6 where it is reflected back to mirror 5a and reaches blazed grating 7. The blazing angle of this grating is selected to deviate the measurement beam in a symmetrical way to flat mirror 5b and to the lower surface of object 6. The measurement beam is then again reflected at mirror 5b and passes beam splitter 4 to generate, together with reference beam 3a, an interference pattern on screen 8. A TV camera 9 picks up this pattern which is then processed and evaluated electronically, e.g. after digitization.

Reference numeral 10 identifies a single ray in the measurement beam 3 which is reflected at point 11 of upper object surface 6. The beam deviation by blazed grating 7 ensures that this ray probes the lower surface of object 6 at point 12 which is exactly opposite

to point 11. The optical path difference of ray 10 with respect to the corresponding ray 10a in the reference beam 3a thus depends only on the distance d between points 11 and 12 such that the interference pattern is entirely determined by the thickness of sample 6.

The angle of incidence α, the separation D of mirrors 5a, 5b and the deflection angle of blazed grating 7 are interdependent and must be chosen in accordance with the reflecting properties of sample 6. For rough surfaces the angle α should have a value of greater than 75° to obtain a specular reflection.

The fringe separation x in the interference pattern that corresponds to a thickness variation δ is given by

$$\delta = \lambda/2x \cos \alpha.$$

The interference pattern can be evaluated visually or, with greater precision, by known picture processing devices. If a digital evaluation of the interference pattern is desired as in modern hybrid interferometers one of the plane mirrors 5a, 5b has to be wobbeled in vertical direction (or, alternatively, blazed grating 7 in horizontal direction).

The blazed grating 7 can be manufactured by known holographic methods where a photosensitive plate is placed in the interference field of two collimated beams. This interference field can also be generated in the set-up of Fig. 1 when a second beam opposite to the direction of the reference beam is used for illumination and sample 6 is replaced by a high precision parallel plate. Such holographic gratings diffract the incoming

light with an efficiency of up to 90 % into the desired exit direction.

The interferometric thickness tester described here works also for slightly bent or curved samples; this case is represented in Fig. 2 where ray 20 samples two approximately opposite surface points within mirrors 5a, 5b. Parallelism and plainness of the sample surface, however, cannot be analyzed with this tester; as it is only sensitive to the vertical distance d between opposite surface points.

Fig. 3 shows another preferred embodiment of the invention in which the blazed grating 7 is replaced by a foldable mirror with plane mirrors 30a, 30b pivotably connected by hinge 31. The bisection of foldable mirror 30 with (half) apex angle β is in the symmetry plane of the interferometric set-up together with sample 6. The angle of incidence α, the distance D between flat mirrors 5a, 5b, the position of sample 6 within the symmetry plane and the apex angle β of the folded mirror are interrelated and have to be chosen such that each ray samples exactly opposite points of sample surfaces 6. As angle α also determines the measurement resolution this second embodiment is easily adaptable to various sample characteristics and resolutions. Fig. 4 shows another example for an arrangement with large angles of incidence α. In the embodiment of Fig. 1 a change of angle α requires also a blazed grating with a different grating constant.

The beam path in Fig. 3 is explained by tracing one of the marginal rays 32a, 32b. The incident ray is split at beam splitter 4 into reference ray 32a and measurement ray 32b which impinges on the upper surface of

sample 6 after a first reflection at mirror 5a. Ray 32c reflected at the sample impinges on mirror 30a at point 34 which deflects it perpendicularly to the plane of symmetry to the second of the folded mirrors 30b from which it reaches point 36 of the sample as ray 32e. The ray 32f emanating from point 36 is reflected at plane mirror 5b and interferes as ray 32g with reference ray 32a which travels in the same direction.

The evaluation of the interference pattern is again performed by conventional pattern recognition systems or by electronic phase sensitive processing; in the latter case one of the plane mirrors 5a, 5b is periodically displaced.

PATENT CLAIMS

1. Method for interferometrically determining thickness variations in flat objects, characterized in that each measurement ray (10) in an incident beam (3a) is made to be reflected at symmetrically opposite points (11, 12) on the front and the rear surface of the object (6) before being brought to interference with a coherent reference ray (10a).

2. Apparatus to carry out the method in accordance with claim 1, characterized in that the object (6) is arranged between two parallel flat mirrors (5a, 5b), that a measurement beam (3a) is provided to illuminate the object under an oblique angle of incidence (α) and that the beam regularly reflected at the upper surface of the object is deflected such that it impinges under the same angle of incidence on the rear surface of the object.

3. Apparatus in accordance with claim 2, characterized in that the measurement beam reflected at the object surface is deflected by a blazed grating (7).

4. Apparatus in accordance with claim 2, characterized in that the measurement beam reflected at the object surface is deflected by a pair of folded mirrors (30a, 30b) whose bisector is coincident with the plane of symmetry between the plane mirrors (5a, 5b).

5. Apparatus according to one of the claims 2 to 4, characterized in that the reference beam (3a) and the measurement beam (3b) are obtained from a laser beam (3) which is incident under oblique angle on a beam splitter (4) arranged perpendicularly to the plane mirrors (5a, 5b).

6. Apparatus according to one of the claims 2 to 5, characterized in that phase sensitive means are provided to evaluate the interference pattern generated from the superposition of reference and measurement beam and that one of the plane mirrors (5a, 5b) is displaced periodically.

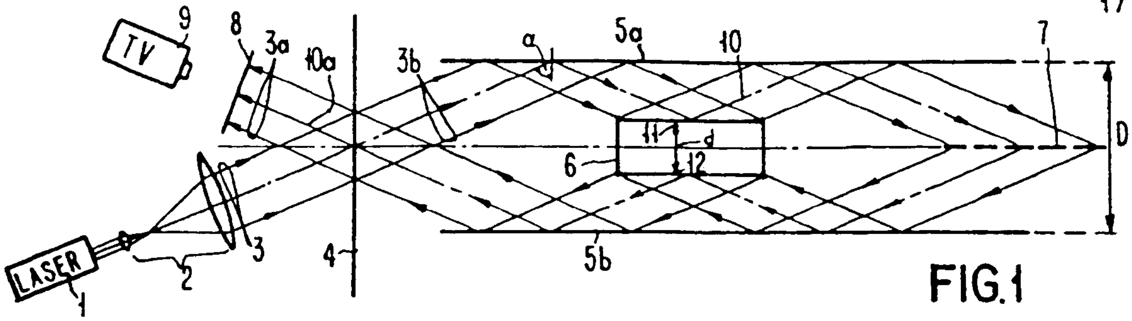


FIG.1

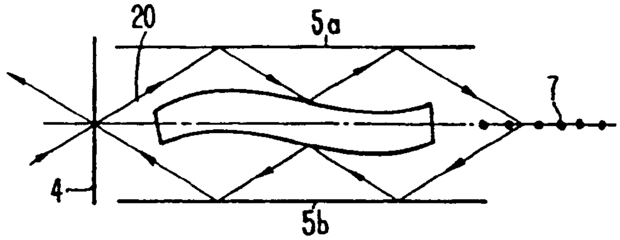


FIG.2

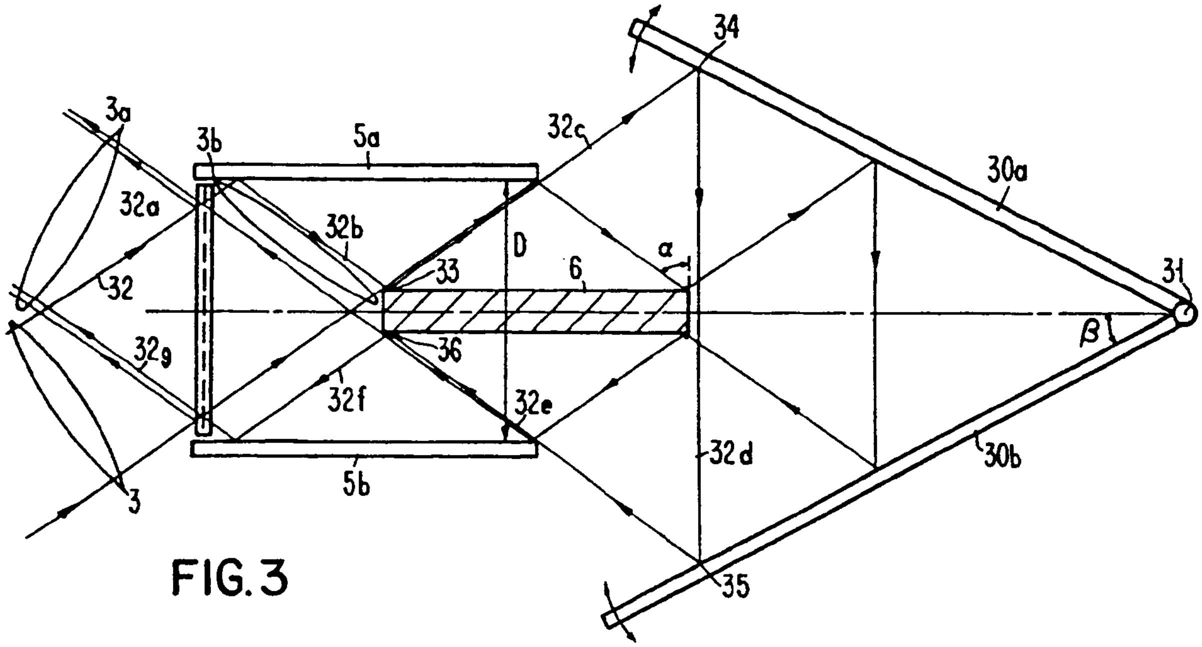


FIG.3

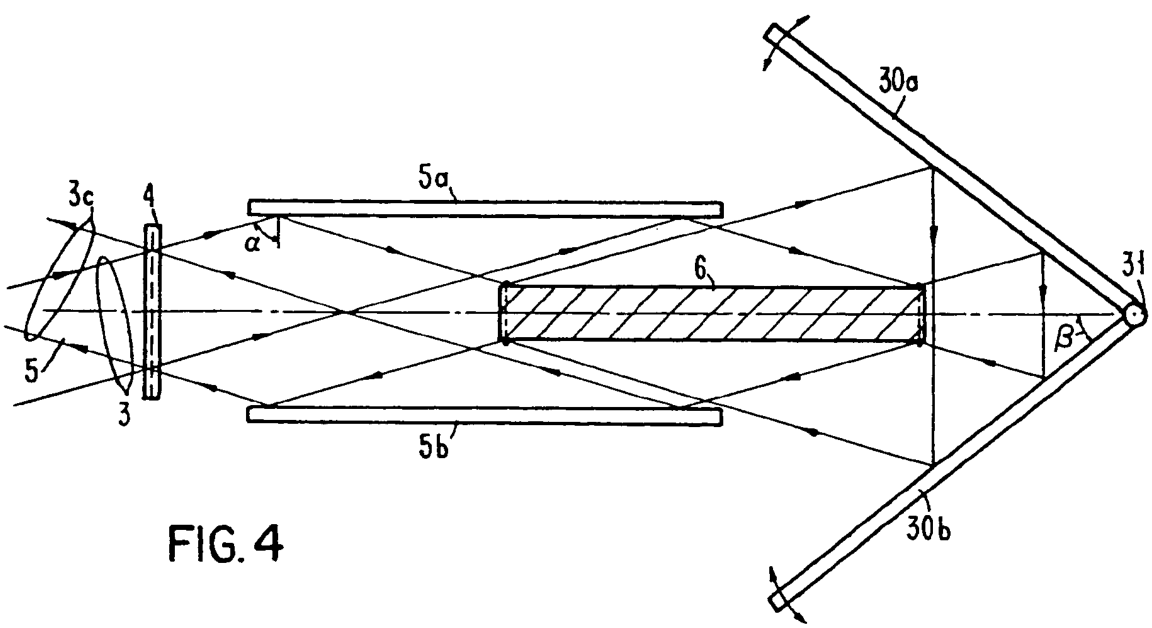


FIG.4

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EUROPEAN SEARCH REPORT

0179935

Application number

EP 84 11 3059

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	NL-A-7 404 593 (STICHTING REACTOR CENTRUM NEDERLAND) * Introduction; page 3, line 2 - page 4, line 31 * ---	1,2,4, 5	G 01 B 11/30 G 01 B 11/06 G 01 B 9/02
X	APPLIED OPTICS, vol. 21, no. 10, May 1982, pages 1732-1737, New York, US; J.A. MONJES et al.: "Reflection-transmission phase shift: interferometer and viewing optics" * Figures 2,4; pages 1734-1735; paragraphs III,IV * ---	1	
A	FR-A-1 562 548 (CENTRE NATIONAL DE RECHERCHES METALLURGIQUES) * Figures 1-4; whole description * ---	1,2	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	DE-A-2 803 466 (E. DEBLER) * Figures 3,5,7; page 5, paragraph 5 - page 6, paragraph 1; page 6, paragraph 4 - page 7, paragraph 1 * -----	2	G 01 B 9/00 G 01 B 11/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	04-07-1985	VISSER F.P.C.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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